ARMY RESEARCH LABORATORY

Team Mental Model and Team Behavior as a Function of Interface Modality

by Bruce S. Sterling and Chuck H. Perala

ARL-TR-3735 **March 2006**

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14. ABSTRACT

This experiment examined the relationship among team mental models, requesting or providing information, and teamwork behavior. Previous studies have suggested that similar mental models among team members lead to information and action being provided before they are requested, thus facilitating teamwork behavior such as communication, coordination, performance monitoring and backup, and adaptation. In this experiment, U.S. Army second lieutenants were presented with field scenario vignettes and asked to complete a written mental model of the most important task, biggest problems, and actions needed for themselves and other platoon leaders. Independent raters evaluated the participants while they were engaged in dialogue via text-based "chat," which was coded for "providing versus requesting" information or action, and teamwork behavior.

Results showed good inter-rater reliability for the measures of mental models, anticipation ratio (providing versus requesting information or actions) and teamwork behavior, suggesting that these concepts were reliably measured. However, no significant relationships were observed among mental models, anticipation ratio, and teamwork behavior. Various methodological reasons are explored as possible explanations for the lack of relationships observed among the factors of interest.

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team behavior; team mental model; teamwork

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1. Introduction

In order for the U.S. Army future force to succeed, that force will have to "see first, understand first, and act first" (Department of the Army, 2003). Compared to the current force, the future force systems will need to be much lighter and smaller to enhance their deployment capability. Thus, in order to increase Soldier survivability, the future force must use sensors, including unmanned aerial vehicle (UAV) system(s) and unmanned ground vehicle (UGV) system(s) to see the enemy at a distance (see first). The future force must then use networked battle command and an integrated interface to provide the common operational picture (COP) to all platforms (understand first). Finally, the future force must use their agility and precision and long-range fires in order to engage the enemy at a time and place dictated by the future force (act first).

The Future Combat System (FCS) operational and organizational (O&O) plan emphasizes collaborative planning and execution, particularly among leaders, in order to see first, understand first, and act first (U.S. Army Training and Doctrine Command, 2002). This collaborative planning and execution is enabled by the use of shared mental models. That is, Soldiers must have a common understanding about those areas for which the plan requires information so that assets which enable the force to see first can be properly deployed. The unit as a whole must have a common understanding about the current situation and the potential problems in each other's areas of responsibility so that the unit understands first. This common understanding, or team mental model, enables the unit to act first, not as uncoordinated individuals or sub-units but as a cohesive ensemble.

Cooke, Salas, Cannon-Bowers, and Stout (2000) define "team mental models" as encompassing the collective task and team relevant knowledge that team members bring to a situation. They can include knowledge of team member roles and responsibilities, knowledge of teammates' knowledge, skills and abilities, cue-strategy associations, understanding of task procedures, and knowledge of typical task strategies. Team situation models refer to team members' collective understanding of the current situation at any specific point in time. It is necessarily a dynamic (changing) understanding. Research by Stout, Cannon-Bowers, Salas, and Milanovich (1999) using a flight simulation task, showed that teams with more similar team mental models did better planning, "pushed" more information (i.e., provided information without it having to be requested) (Serfaty, Entin, & Johnston, 1998), and made fewer errors. Mathieu, Goodwin, Heffner, Salas, and Cannon-Bowers (2000) showed that team mental model congruence was positively related to team processes and team performance in a flight simulation task. In a simulated armor platoon task, Marks, Zaccaro, and Mathieu (2000) found that team mental model similarity was positively related to team processes and in novel situations, to team performance.

However, teams can only have mental models based on information possessed by individual team members. Enhancing individual information processing through more effective information cues may affect team performance because of its enhanced effect on the team (shared) mental model.

Wickens' (2002) model of multiple resources and performance prediction suggests that presenting information in multiple modalities (e.g., visually and aurally) is more effective than presenting the same information all in the same modality (visually or aurally). Grohn, Lokki, and Takala (2003), in a three-dimensional (3-D) navigation task, showed that visual and auditory cues resulted in better performance than visual or auditory cues alone. Skilling, Morgan, Mosbruger, Belstein, and Orichel (2003), in a simulated air traffic controller task, found that simulated aircraft were located more rapidly with visual and 3-D audio than with visual or auditory cues alone. It is likely that both navigation and air traffic control require formation of a mental model. Thus, enhancing the salience of information to individuals may result in improved team mental models, which in turn may improve teamwork behavior.

It was our hypothesis that team mental models lead to anticipation (pushing information or providing information before it is requested), which in turn leads to more effective team behavior. It was further posited that this formation of mental models and subsequent team behavior may be affected by the modality in which the information is presented. For example, an audio cue used to introduce information may increase the salience of the information and therefore help provide a better team mental model.

2. Method

2.1 Participants

Twenty U.S. Army active duty second lieutenants (all male) were randomly assigned to ten two-person teams. Participants had current training in the Armor Officer Basic Course from Fort Knox, Kentucky, but had no experience as platoon leaders.

2.2 Instrumentation

Experimentation was conducted with three laptop computers running a custom-built, interactive user interface that presented visual-only and visual-plus-audio vignettes to each participant, and three networked computers using Microsoft[1] Word[1] and Army Knowledge Online (AKO) chat.

[1]Microsoft and Word are trademarks of Microsoft Corporation.

2.3 Measures

Measures included in this study were team mental models, anticipation ratios, and teamwork behavior. Each is described in detail in the following sections.

2.3.1 Team Mental Model

For each vignette, participants completed a team mental model matrix by listing the most important current task, biggest potential problem, and action needed for each of the three platoon leaders. Each participant's team mental model was scored against the other participant's mental model and against "ground truth" (an assessment of the tactical situation made by subject matter experts [SMEs]). Scores for each of the entries in the table were 0, 1, and 2, for not at all similar, somewhat similar, and identical, respectively. Total scores could range from 0 to 18 per participant for both team mental model and ground truth mental model. Ground truth and team mental model scores were provided by two civilian raters (employees of the U.S. Army Research Laboratory [ARL], who had military experience) blind to the experimental conditions. Inter-rater reliabilities for the two raters were computed with Pearson correlations. Consensus ratings of the mental model were correlated with measures of anticipation ratio and teamwork behavior. The mental models used were team mental model, ground truth for each participant, and total ground truth (sum of ground truth for both participants). See appendix A for ground truth mental models for each of the three vignettes.

2.3.2 Anticipation Ratio

All AKO chat communications were stratified (if relevant) by request information, request action, provide information, and provide action. All relevant (e.g., not acknowledgments) dialogue was scored by two U.S. Army noncommissioned officers (NCOs) who were blind to experimental conditions and not exposed to participants' mental models. Anticipation ratios were calculated as shown in table 1.

Table 1. Anticipation ratios.

Request	Provide
Information (e.g., what is your current situation?)	Information (e.g., I am south of the bridge)
Action (e.g., engage enemy vehicles to your front)	Action (e.g., I am preparing to engage enemy vehicles to my front)

2.3.3 Teamwork Behavior

Team members communicated via synchronous, text-based, chat (using AKO chat). The experiment was designed to look for four types of teamwork behavior: communication, coordination, performance monitoring and backup, and adaptation. Specific teamwork behavior for each of the three vignettes is presented in appendix B. These teamwork behaviors were also scored by two ARL employees with military experience who were blind to the experimental condition and blind to which set of dialogue was associated with which mental model.

2.4 Procedure

The experiment took place in the ARL offices at Fort Knox. Experiments were run with teams of two second lieutenants. Each participant was randomly assigned to be a mounted combat system (MCS) platoon leader or reconnaissance and surveillance (RSV) platoon leader in a combined arms company. The experimenter played the roles of infantry combat vehicle (ICV) platoon leader and company commander.

Participants were provided with background information concerning systems and capabilities in operation during each vignette and a brief operations order (OPORD). Most of this information conformed to the FSC operational requirements document (ORD). However, some of the information was constructed by the experimenter because some values and parameters were classified. Participants were asked to use the information presented to them in this experiment as "truth" for this experiment only. See appendix C for the background information presented to participants.

A brief multiple choice test was given to determine if the participants understood this information. All questions were correctly answered before we proceeded. If the participants answered any item incorrectly, they were given more time to review each system and its capability before being re-tested on that item(s). See appendix D for the multiple choice test.

Teams were randomly assigned to a visual-only or visual-plus-audio condition. All participants were first presented with the "baseline" vignette on the laptop computer, which consisted of a terrain map with pre-positioned, standard military symbology (per MIL-STD-2525B). In the visual-only condition, icons appeared on the map approximately 5 seconds apart and remained on the screen for the duration of the vignette (figure 1). These icons represented entities such as vehicles, force elements (e.g., battalions, platoons, companies), and personnel (e.g., refugees). The entity icons were color coded as friendly (blue), coalition (orange), enemy (red), and unknown (yellow). At any time, when the mouse pointer was moved over each icon (and held for longer than 1 second), a text-based comment box appeared next to the icon, providing additional information (figure 2). This included type, size, and, if applicable, armament and status.

In the visual-plus-auditory condition, entity icons appeared on the map approximately 5 seconds apart and remained on the screen for the duration of the vignette (in the same manner and form as in the visual-only condition). However, in this condition, an auditory cue accompanied each icon as it appeared. This auditory cue was in the form of a digitized male voice and provided information about the entity such as type and size. Auditory examples include "vehicle, enemy, tank," "platoon, friendly, ICV," and "refugees, quantity, 150". At any time, when the mouse pointer was moved over each icon (and held for longer than 1 second), the auditory information was replayed and a text-based comment box appeared next to the icon, reinforcing the auditory information. This information included type, size, and, if applicable, armament and status.

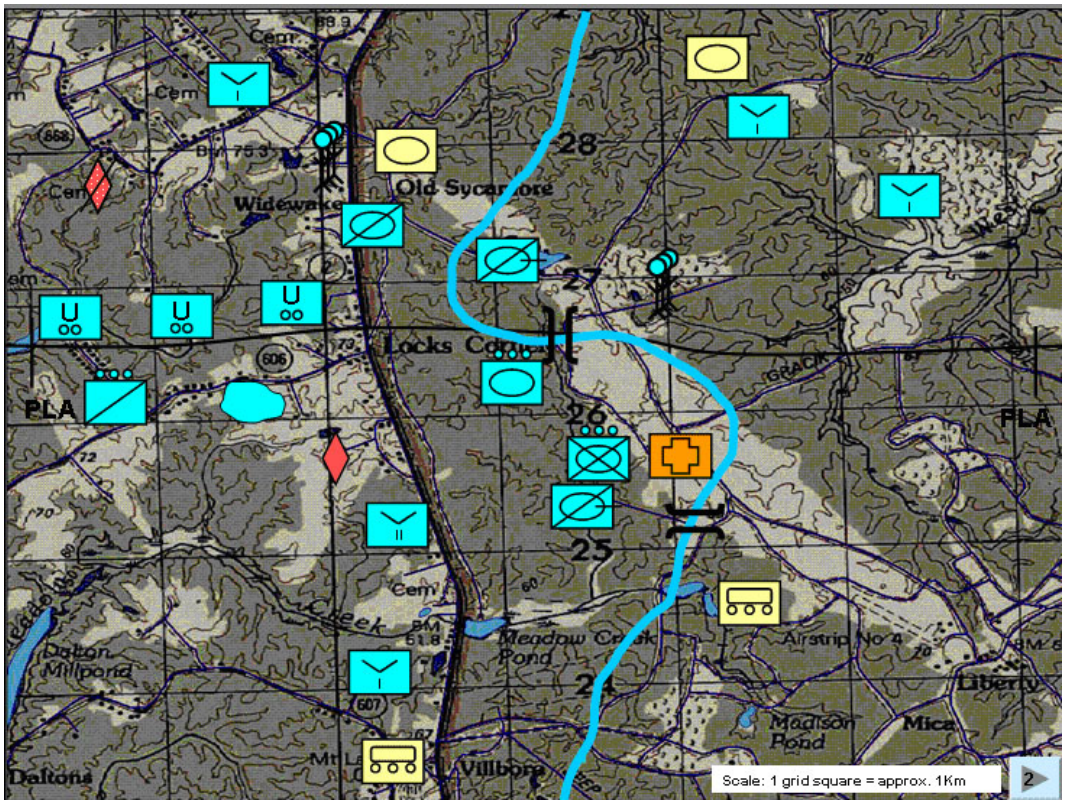

Figure 1. Visual-only interface.

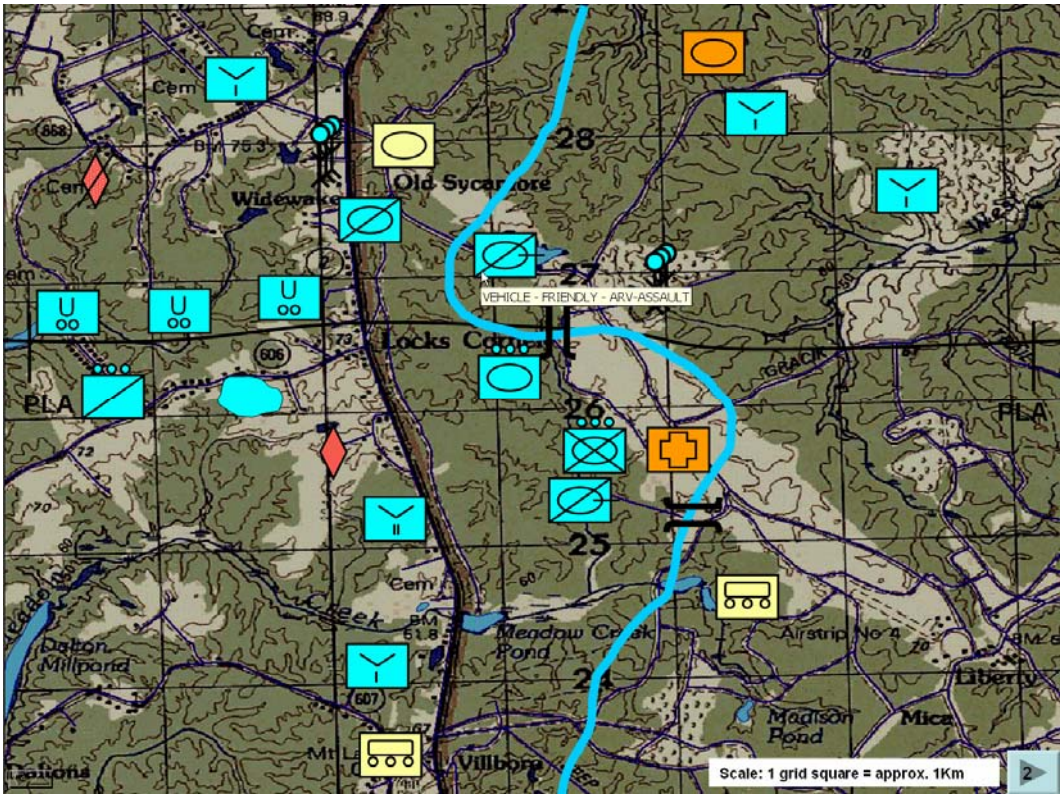

Figure 2. Visual-only interface with entity information provided by mouse-over text box.

The baseline vignette consisted of all the vehicles in the company in the positions described in the abbreviated OPORD. After studying the baseline vignette for 5 minutes, participants were then presented with first vignette on their laptop computer screens and asked to study the situation for 5 minutes. They were then asked to complete a team mental model matrix (in Microsoft Word on a desktop computer) for that vignette. Following completion of the mental model matrix, participants interacted with each other via AKO chat (also on the desktop computer) for 5 minutes. If participants did not take the "correct" actions (as determined by the experimenters), the company commander (experimenter) then directed them to "take the correct actions," so that the screen for the next vignette would appear logical, based on actions "taken" in the previous vignette. See appendix E for descriptions of the three vignettes.

Participants executed the second and third vignettes and performed the same tasks for each (study the situation, complete the mental model, and collaborate on AKO) in the same manner previously described. The experimenter then thanked and excused the participants.

Since the vignettes proceeded in a logical sequence, counter-balancing vignette order was not feasible. The three vignettes formed one scenario that was presented identically to all participants and was thus not an independent variable.

2.5 Analysis

Between-subject t-tests were used to test for significant differences between the visual-only and visual-plus-auditory conditions. Pearson bivariate correlations were used to test for significant linear relationships among the mental model anticipation ratio and teamwork variables. Partial correlations, controlling for the effect of mental model (team and ground truth) were used to test for significant linear relationships between anticipation ratio and teamwork behavior. These correlations are generally used in the literature to test for relationships between mental models and teamwork variables.

3. Results

3.1 Demographics

The participants were 20 male second lieutenants with no experience as platoon leaders. Nineteen were from the armor branch and one (in the visual-only condition) was from the signal branch. All had recently graduated from the Armor Officer Basic Course, and six were currently in the Scout course (two in the visual-only condition and four in the visual-plus-auditory condition). Overall, the participants averaged 37.3 months active duty time (41.3 months for the visual-only condition and 33.3 months for the visual-plus-auditory condition). The difference between conditions for time in the Army was not statistically significant ($F_{1,18} = 0.19$, $p = 0.67$).

3.2 Test Items

Overall, the participants achieved 88% accuracy on the first try (13.15 of the 15 items correct). Those in the visual-only condition had 13.20 items correct, and those in the visual-plus-auditory condition had 13.10 items correct. The difference between the two conditions was not statistically significant ($F_{1,18} = 0.015$, $p = 0.90$).

3.3 Inter-Rater Reliability

Overall inter-rater reliability was good. Of the 15 total correlations, 11 were statistically significant and one approached statistical significance, even with only 10 observations (two-person teams). All inter-rater reliability correlations were statistically significant for vignette 1, and three were significant for vignettes 2 and 3 (table 2).

Table 2. Inter-rater reliabilities.

Rating	Vignette 1	Vignette 2	Vignette 3
Team Mental Model	.74 .015*	.71 .022*	.61 .059
Ground Truth Model - MCS	.88 .001*	.91 .001*	.21 ns
Ground Truth Model - RSV	.86 .002*	.88 .001*	.83 .003*
Teamwork	.80 .006*	-.16 ns	.78 .008*
Anticipation Ratio	.96 .001*	.41 ns	.92 .001*

*Statistically significant effect at $p \leq 0.05$.

3.4 Team Mental Model, Anticipation Ratio, and Team Behavior by Vignette

Since there were no statistically significant differences between the visual-only and visual-plus-auditory conditions as described next, correlations were calculated for the entire sample. Tables 3 through 5 show results of the correlation analyses of the factors of interest. No correlations between team mental model and anticipation ratio or team mental model and teamwork behavior even approached statistical significance. There was one correlation between anticipation ratio and a teamwork behavior (coordination) that was statistically significant in vignette 2, but this hardly establishes a reliable relationship between anticipation ratio and teamwork. Most of the statistically significant relationships were among teamwork behavior. In vignette 1, communication and coordination were significantly and positively correlated. However, any relationships between total teamwork and teamwork behavior can be discounted, since total teamwork was the sum of the separate teamwork behavior. Thus, there was not a consistent pattern of relationships among teamwork behavior. In vignette 3, no correlations of any variable with communication are reported because communication has no variance in this vignette (all teams had a score of 2). Also in vignette 3 there was no coordination behavior. Adaptation behavior occurred only in vignette 3.

Table 3. Team mental model, anticipation ratio, and team behavior – vignette 1.

	Team Mental Model (TMM)	**Anticipation Ratio (AR)**	**Communication (CM)**	**Coordination (CD)**	**Performance Monitoring (PF)**	**Total Teamwork (TW)**
TMM	-	-.17 ns	.24 ns	.22 ns	-.20 ns	.03 ns
AR	-.17 ns	-	.06 ns	-.22 ns	-.33 ns	-.27 ns
CM	.24 ns	.06 ns	-	.72 .019*	.43 ns	.78 .007*
CD	.22	-.22 ns	.72 .019*	-	.35 ns	.79 .007*
PF	-.20 ns	-.33 ns	.43 ns	.35 ns	-	.83 .002*
TW	.03 ns	-.27 ns	.78 .007*	.79 .007*	.83 .003*	-

*Statistically significant effect at $p \leq 0.05$.

Table 4. Team mental model, anticipation ratio, and team behavior – vignette 2.

	Team Mental Model (TMM)	**Anticipation Ratio (AR)**	**Communication (CM)**	**Coordination (CD)**	**Performance Monitoring (PF)**	**Total Teamwork (TW)**
TMM	-	.00 ns	.41 ns	-.23 ns	-.18 ns	-.14 ns
AR	.00 ns	-	-.04 ns	.66 .037*	.00 ns	.42 ns
CM	.41 ns	-.04 ns	-	-.17 ns	.23 ns	.24 ns
CD	-.23 ns	.66 .037*	-.17 ns	-	.46 ns	.83 .003*
PF	-.18 ns	.00 ns	.23 ns	.46 ns	-	.84 .003*
TW	-.14 ns	.42 ns	.24 ns	.83 .003*	.84 .003*	-

*Statistically significant effect at $p \leq 0.05$.

Table 5. Team mental model, anticipation ratio, and team behavior – vignette 3.

	Team Mental Model (TMM)	**Anticipation Ratio (AR)**	**Performance Monitoring (PF)**	**Adaptation (AD)**	**Total Teamwork (TW)**
TMM	-	.36 ns	-.14 ns	.20 ns	.24 ns
AR	.36 ns	-	-.26 ns	-.38 ns	-.53 ns
PF	-.14 ns	-.26 ns	-	-.31 ns	.20 ns
AD	.30 ns	-.38 ns	-.31 ns	-	.87 .001*
TW	.24 ns	-.53 ns .001*	.20 ns	.87 .001*	-

*Statistically significant effect at $p \leq 0.05$.

3.5 Ground Truth Mental Model, Anticipation Ratio, and Team Behavior by Vignette

There were no consistent relationships between ground truth mental models and anticipation ratio or ground truth mental models and teamwork. In the first vignette, ground truth for the RSV participant was significantly and negatively correlated with performance monitoring and total teamwork behavior. In the second vignette, the correlation between total ground truth and anticipation ratio approached significance. In the third vignette, ground truth for the MCS participant was significantly and positively correlated with adaptation and approached significance in the negative direction with performance monitoring. Also, the correlation between total ground truth and adaptation approached significance. As might be expected, there were some significant correlations between total ground truth and ground truth for MCS and RSV participants, but these correlations can be discounted since total ground truth is the sum of ground truth for MCS and RSV participants (tables 6 through 8).

Table 6. Ground truth mental model, anticipation ratio, and team behavior – vignette 1.

	Ground Truth MCS (GM)	Ground Truth RSV (GR)	Total Ground Truth (GT)	Anticipation Ratio (AR)	Communication (CM)	Coordination (CD)	Performance Monitoring (PF)	Total Teamwork (TW)
GM	-	-.50 ns	.61 .062	-.40 ns	.46 ns	.38 ns	.34 ns	.47 ns
GR	-.50 ns	-	.38 ns	.49 ns	-.43 ns	-.37 ns	-.73 .016*	-.69 .029*
GT	.61 .062	.38 ns	-	.03 ns	.10 ns	.07 ns	-.31 ns	-.13 ns
AR	-.40 ns	.49 ns	.03 ns	-	.06 ns	-.22 ns	-.33 ns	-.27 ns
CM	.46 ns	-.43 ns	.10 ns	.06 ns	-	.72 .019*	.43 ns	.78 .007*
CD	.38 ns	-.37 ns	.07 ns	-.22 ns.	72 .019*	-	.35 ns	.79 ,007*
PF	.34 ns	-.73 .016	-.31 ns	-.33 ns	.43 ns	.35 ns	-	.83 .003*
TW	.47 ns	-.69 .029	-.13 ns	-.27 ns	.78 .007*	.79 .007*	.83 .003*	-

*Statistically significant effect at $p \leq 0.05$.

Table 7. Ground truth mental model, anticipation ratio, and team behavior – vignette 2.

	Ground Truth MCS (GM)	Ground Truth RSV (GR)	Total Ground Truth (GT)	Anticipation Ratio (AR)	Communication (CM)	Coordination (CD)	Performance Monitoring (PF)	Total Teamwork (TW)
GM	-	-.14 ns	.64 .048*	.32 ns	-.39 ns	.25 ns	.11 ns	.12 ns
GR	-.14 ns	-	.68 .031*	.42 ns	.41 ns	.12 ns	-.28 ns	.03 ns
GT	.64 .048	.68 .031*	-	.56 .089	.03 ns	.28 ns	-.14 ns	.12 ns
AR	.32 ns	.42 ns	.56 .089	-	-.04 ns	.66 .037*	.00 ns	.42 ns
CM	-.39 ns	.41 ns	.03 ns	-.04 ns	-	-.17 ns	.23 ns	.24 ns
CD	.25 ns	.12 ns	.28 ns	.66 .037*	-.17 ns	-	.46 ns	.83 .003*
PF	.11 ns	-.28 ns	-.14 ns	.00 ns	.23 ns	.46 ns	-	.84 .003*
TW	.12 ns	.03 ns	12 ns	.42 ns	.24 ns	.83 .003*	.84 .003*	-

*Statistically significant effect at $p \leq 0.05$.

Table 8. Ground truth mental model, anticipation ratio, and team behavior – vignette 3.

	Ground Truth MCS (GM)	Ground Truth RSV (GR)	Total Ground Truth (GT)	Anticipation Ratio (AR)	Performance Monitoring (PF)	Adaptation (AD)	Total Teamwork (TW)
GM	-	-.30 ns	.44 ns	-.20 ns	-.61 .064	.73 .016*	.44 ns
GR	-.30 ns	-	.73 .018*	.14 ns	.21 ns	.03 ns	.14 ns
GT	.44 ns	.73 .018*	-	-.47 ns	-.24 ns	.56 .09	.14 ns
AR	-.20 ns	-.35 ns	-.47 ns	-	-.26 ns	-.38 ns	-.53 ns
PF	-.61 .064	.21 ns	-.24 ns	-.26 ns	-	-.31 ns	.20 ns
AD	.73 .016*	.21 ns	.56 .094	-.38 ns	-.31 ns	-	.87 .001*
TW	.44 ns	.14 ns	.45 ns	-.53 ns	.20 ns	.87 .001*	-

*Statistically significant effect at $p \leq 0.05$.

3.6 Anticipation Ratio With Teamwork, Controlling for Team Mental Model

There was no consistent pattern of relationships between anticipation ratio and teamwork behavior, controlling for the effect of team mental model. As discussed previously, anticipation ratio was significantly and positively related to coordination in vignette 2. Also, with the effects of team mental model removed, anticipation ratio was significantly and negatively related to total teamwork in vignette 3. However, no overall pattern is evident (table 9).

Table 9. Anticipation ratio with teamwork, controlling for team mental model.

Anticipation Ratio	Communication	Coordination	Adaptation	Performance Monitoring	Total Teamwork
Vignette 1	.10 ns	-.19 ns	-	-.37 ns	-.27 ns
Vignette 2	-.04 ns	.68 .045*	-	.00 ns	.42 ns
Vignette 3	-	-	-.55 ns	-.22 ns	-.68 .045*

*Statistically significant effect at $p \leq 0.05$.

3.7 Anticipation Ratio With Teamwork, Controlling for Ground Truth Mental Model

There were no statistically significant correlations between anticipation ratio and teamwork behavior, controlling for the effects of ground truth mental model. The previously discussed correlation between anticipation ratio and coordination in vignette 2 closely approached statistical significance (table 10).

Table 10. Anticipation ratio with teamwork, controlling for ground truth mental model.

Anticipation Ratio	Communication	Coordination	Adaptation	Performance Monitoring	Total Teamwork
Vignette 1	.43 ns	.00 ns	-	.05 ns	.14 ns
Vignette 2	-.12 ns	.65 .082	-	.12 ns	.44 ns
Vignette 3	-	-	-.22 ns	-.52 ns	-.42 ns

*Statistically significant effect at $p \leq 0.05$.

3.8 Comparison of Visual-Only and Visual-Plus-Auditory Conditions

There were no statistically significant ($p < 0.05$, two-tailed test) differences between the visual-only and visual-plus-auditory condition for any variable measuring mental model, anticipation ratio or teamwork behavior, for any vignette (tables 11 through 13). Ground truth for the RSV participants approached statistical significance on vignette 1 (t_8, $p = 0.09$).

Table 11. Comparison of visual-only and visual-plus-auditory conditions - vignette 1.

Dependent Variables	Visual-Only	Visual-plus-Auditory
Team Mental Model	7.2	6.4
Ground Truth Mental Model - MCS	12.6	7.8
Ground Truth Mental Model - RSV	9.8	14.2
Communication	4.0	3.6
Coordination	2.6	2.0
Performance Monitoring	2.8	1.2
Total Teamwork	9.4	7.0
Anticipation Ratio	2.3	4.4

Table 12. Comparison of visual-only and visual-plus-auditory conditions - vignette 2.

Dependent Variables	Visual-Only	Visual-plus-Auditory
Team Mental Model	7.0	10.2
Ground Truth Mental Model - MCS	11.2	12.2
Ground Truth Mental Model - RSV	12.4	13.4
Communication	8.0	7.4
Coordination	4.0	3.4
Performance Monitoring	2.4	1.6
Total Teamwork	14.4	12.4
Anticipation Ratio	2.2	1.8

Table 13. Comparison of visual-only and visual-plus-auditory conditions - vignette 3.

Dependent Variables	Visual-Only	Visual-plus-Auditory
Team Mental Model	6.3	6.6
Ground Truth Mental Model - MCS	9.0	10.2
Ground Truth Mental Model - RSV	8.2	9.2
Communication	2.0	2.0
Performance Monitoring	.6	.4
Adaptation	2.4	4.0
Total Teamwork	5.0	6.0
Anticipation Ratio	3.3	1.5

4. Discussion

The measures of mental models (both team and ground truth), anticipation ratio, and teamwork behavior appear to be reliable, based on the high inter-rater reliability results. The separate components of teamwork were not highly inter-correlated, which could suggest that they were in fact, as intended, measuring separate components of teamwork.

However, in this research, the mental models were not reliably related to anticipation ratio or teamwork behavior. Also, anticipation ratio was not reliably related to teamwork behavior, regardless whether mental models were held constant.

There is sufficient literature in this area to suggest that relationships among these concepts likely do exist. Thus, why were they not found in this experiment? The measure of mental model expected participants to speculate about tasks, problems, and actions needed in the imminent vignette. The measure of teamwork behavior generally documented the actions actually taken during the vignette or at least whether the actions were "correct" in the mind of a SME. Perhaps when the vignette began and the participants began exchanging messages, their ideas of what they would do were overtaken by events and were thus unrelated to what they had recorded earlier as their mental models. In fact, there was one team with extremely low mental model scores on vignette 1 that scored 100% on teamwork behavior in the same vignette. Thus, perhaps the participants' mental model before the vignette was not related to their actions during the vignettes.

Another possibility is the inexperience of the participants. All participants were the least experienced of officers in terms of time in grade, time in service, and on-the-job experience (i.e., none had been actual platoon leaders). Thus perhaps they were unaccustomed to thinking about what they would do in a tactical situation and had relatively poor mental models. In fact, the ground truth mental models for all three vignettes had a mean of 60% of the possible score. Thus their mental models of what they would do may not have been as reliable a prediction of the behavior (teamwork behavior) as would be the mental models of more experienced tacticians. In fact, Swain and Mills (2003) found that expert teams used more implicit communication (i.e., providing information without being asked) than novice teams, which they attributed to using a team mental model of both the roles of team mates and how they should be working together in a group situation.

Also, unlike other experiments, the degree to which information or actions were "pushed" versus "pulled" did not relate to teamwork behavior. Perhaps one reason for this was that, unlike other experiments, both participants here had identical information. While actions could certainly be both provided (pushed) or requested (pulled), there was little need to ask for "pull" information. Thus perhaps these scenarios did not provide enough impetus to pull information, thus inflating

anticipation ratios. In fact, the anticipation ratios for all three vignettes were more than one, which indicates that providing rather than requesting information or actions was the norm.

There were no significant differences between visual-only and visual-plus-auditory presentation of the information. Besides the small number of teams (five in each condition), perhaps a reason for this is that no new information was presented during the vignette—only modality was changed. The participants had time to study the vignettes, with all information present, before the dialogue that was the basis of teamwork behavior began. Perhaps the addition of audio is most useful to drawing attention to new information presented while participants are distracted from noticing a visual presentation only by ongoing tasks. That is, enough of their attentional resources were available to perceive and cognitively process the information provided, without the need for a secondary stimulus mode (in this case, auditory cues) to compensate for a more highly taxed resource pool.

In summary, it is felt that methodological incongruities in this experiment contributed to the lack of observed significance between mental models, information and action pushing or pulling, and teamwork behavior. It is further believed that leader experience may have a significant impact on mental model development and subsequent inter-relationship among information sharing and teamwork behavior and thus may warrant further investigation.

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Appendix A. Ground Truth Mental Models for All Vignettes

Vignette 1: Team Mental Model—Scoring Criteria

Position	Most important current task	Potential Problem	Action needed
Recon platoon	Protect RCP	No fires capable of destroying tank *If action needed (next column) clearly indicates that they understand they cannot kill tank, score potential problem as "2"*	Have MCS platoon use BLOS to destroy tank
MCS platoon	1) Identify vehicles to north, unidentified armor in sector 2) Defend –secure bridge	Sensor not close enough *If action needed (next column) clearly indicates that they understand they need to move the sensor close, scorer potential problem as "2"*	Have Recon platoon move sensor closer or ID vehicle/armor
ICV platoon	Move to rendezvous with Red Cross vehicles	1) Unknown vehicle by bridge *2) unknown in south of sector*	1) Positively ID and destroy (if necessary) vehicle by bridge or *in south of sector, 2)linkup,protect/escort Red Cross*

Vignette 2: Team Mental Model

Position	Most important current task	Problem	Action needed
Recon platoon	1) Collect refugees in area of unknown vehicle *2) Protect RPC (from enemy tank)*	Unknown tracked vehicle (possibly enemy tank) in area	ID vehicle, MCS vehicle to engage enemy vehicle if vehicle identified as enemy or *MCS destroy tank with BLOS*
MCS platoon	1) Protect RPC from enemy tank 2) Defend in sector	Tank in area of RPC refugees	1) Kill tank 2) Request scouts to pick up refugees
ICV platoon	Accompany Red Cross convoy to RCP	1) Enemy tank in vicinity 2) ID-track unknown wheeled vehicle to south	1) BLOS fires to destroy tank and/or ID vehicle in south, 2) Face to face linkup w/IRC

Vignette 3: Team Mental Model

Position	Most important current task	Problem	Action needed
Recon platoon	Protect, guard, defend, secure RCP or destroy enemy north of PLA	Enemy company north of PL A or outnumbered by enemy	1) Consolidate RSV assets; 2) Coordinate with MCS, ICV and coalition forces to defend (attack) enemy infantry in north
MCS platoon	1) Protect bridge or cover flank, 2) Assist RCP	Threat to flank from dismounts	1) Orient and coordinate with own 2) Coordinate with coalition forces
ICV platoon	1) Offensive (defensive) operations against pending enemy threat (enemy infantry in north), 2) IRC security	1) Threat to RPC 2) U/I vehicle to south	1) Need to link up with RSV, MCS and coalition forces to attack (defend) threat to RPC 2) Assist IRC convoy.

Appendix B. Teamwork Behavior by Vignette

Vignette 1

Teamwork Behavior	Description	Score (0, 1, 2)
Communication	Unknown tracked vehicle in north of MCS sector	
Communication	Enemy tank in RSV sector	
Coordination	Move UAV (provide coverage) for tank in north of MCS sector (if request made by MCS PL one point; if made by RSV PL two points)	
Coordination	MCS platoon to destroy enemy tank in RSV sector via BLOS engagement (if request made by RSV PL one point; if made by MCS PL two points)	
Performance monitoring and backup	ICV platoon needs to link up with Red Cross convoy (leave unidentified truck in south alone)	
Performance monitoring and backup	ICV platoon needs to identify unknown vehicle(s) by bridge and in south of ICV sector (one point if refer to only one vehicle, two points if refer to two vehicles)	

Vignette 2

Teamwork Behavior	Description	Score (0, 1, 2)
Communication	Refugees in MCS sector	
Communication	Refugees in RSV sector (sending out vehicle)	
Communication	Unknown armor in RSV sector near refugees (RSV will ID)	
Communication	Enemy tank in ICV sector near RCP	
Communication	Talk with coalition tank in north (e.g., why they are there, are they aware of friendly forces in area, etc.)	
Performance Monitoring and Backup	MCS indicates RSV needs to ID unknown vehicle in RSV sector near refugees	
Coordination	RSV platoon needs to dispatch vehicle to rendezvous with refugees in MCS area (if request made by MCS PL one point, if made by RSV PL two points)	
Coordination	MCS platoon needs to destroy enemy tank near RCP (if request made by RSV PL one point, if made by MCS PL two points)	
Coordination	MCS platoon needs to be prepared to destroy armored vehicle in RSV sector next to refugees if identified as enemy (if request made by RSV PL one point, if made by MCS PL, two points	
Performance monitoring and backup	ICV platoon needs to identify unknown vehicle in south of ICV sector	

Vignette 3

Teamwork Behavior	Description	Score (0, 1, 2)
Communication	Enemy infantry (company) in RSV sector	
Adaptation	Delay bringing refugees to RCP	
Adaptation	Delay bringing Red Cross to RCP	
Adaptation	Bring some ICV vehicles and dismounts to defend against enemy infantry	
Adaptation	Communicate with coalition tank near refugees to assist in defending against enemy infantry	
Performance monitoring and backup	ICV platoon needs to identify unknown vehicle in south of ICV sector (before Red Cross convoy crosses)	

Appendix C. Background Information for Participants

Descriptions of three FCS Platoons:

Reconnaissance Platoon:
This platoon provides sensors to detect what is in the area of operation, and scouts who are capable of dismounted reconnaissance or dealing with the local populace, such as refugees. The simulated reconnaissance platoon consists of three reconnaissance and surveillance vehicles (RSVs). The vehicles have a two-Soldier mounted crew (vehicle commander and driver). One vehicle has a five-Soldier dismounted complement of scouts. The other two vehicles have a six-Soldier complement of scouts. These scouts are capable of interrogating personnel, as well as engaging enemy personnel with small arms. The RSVs themselves have a 25 mm air burst gun capable of engaging enemy personnel, trucks or light armored vehicles at 1500 m.

Each RSV controls a small unmanned ground vehicle (SUGV), and a class I unmanned aerial vehicle (UAV). The SUGV can be controlled to a distance of 1 km, and can identify targets at distances up to 1 km. The Class I UAV has a control range of 8 km and can identify targets or assist beyond line of sight (BLOS) engagements up to .5 km (500 m).

In addition, one R&SV has a robotic armed reconnaissance vehicle-Reconnaissance (ARV-R). The ARV-R has a control range of 2 km and can identify targets at 1 km. The ARV-R is capable of engaging enemy personnel, trucks or light armored vehicles at 1500 meters.

MCS Platoon:
This platoon provides firepower. It is capable of destroying enemy armor using direct fire or beyond line of sight (BLOS) engagements. BLOS engagements involve linking an MCS vehicle located beyond the line of sight of the target to a sensor which currently has a view of the target. The MCS vehicle can engage the target using sensor feed to put the round on target. The simulated mounted combat system (MCS) platoon consists of three manned vehicles. Each vehicle has a three Soldier mounted crew (vehicle commander, gunner, and crew chief). Each MCS is capable of engaging enemy heavy armored vehicles at a distance of 16 kilometers with beyond line of sight (BLOS) munitions. Each MCS is also capable of engaging enemy armored vehicles at a distance of two kilometers (line of sight only) with its main gun. Using different ammunition, it can also engage lightly armored vehicles or destroy bunkers with the main gun at 2 km. Using appropriate ammunition, the MCS can engage dismounted infantry at 700 meters.

The platoon leader's vehicle also controls a robotic ARV-Assault (A). The ARV-A has a control range of 2 km and can identify targets at 1 km. The ARV-A is capable of engaging heavy armor at 1 km with direct fire, and dismounted infantry at 2 km.

ICV Platoon:
This platoon provides dismounted troops and also sensors. The simulated infantry platoon consists of four infantry carrier vehicles (ICVs) and a command and control vehicle (C2V). The C2V has a three-Soldier mounted crew (vehicle commander, driver, and robotics NCO) plus a platoon leader and medic The C2V controls a robotic armed reconnaissance vehicle-Assault (ARV-A), with capabilities defined above, and a Class II UAV. The Class II UAV has a control range of 16 km and can identify targets at 3 km.

Each of the ICVs has a two-Soldier mounted crew (vehicle commander and driver) and a complement of nine dismounted infantry, capable of engaging enemy personnel with small arms. The ICVs themselves have a 25 mm gun capable of engaging enemy personnel, trucks or light armored vehicles at 1500 meters. The Platoon Sergeant's vehicle also controls a Class I UAV, with the same capabilities of the Reconnaissance Platoon Class I UAV.

Identification ranges of sensors given above are dependent on weather (e.g. rain or fog would limit range) and terrain (e.g., thick vegetation would limit range).

Rules of engagement for each vignette include that an entity must be identified as enemy before being engaged. Coalition forces are considered friendly in this experiment. Unidentified assets are not a software mistake; they are unidentified in this experiment.

Abbreviated Operations Order
Commander's intent: My intent is to guard the refugee collection point (RCP) below phase line alpha (PL A) and collect refugees in that area.

The MCS platoon's primary mission is to defend the bridge in the north against possible enemy armor approaching from the north. The MCS platoon has primary responsibility for the area north of Phase Line Alpha and east of the river

The Reconnaissance platoon must guard the refugees at the RPC and collect other refugees found in the area of operation. The RSV platoon has primary responsibility for the area north of phase Line A and west of the river. The RSV platoon will support the MCS platoon by controlling sensors so the MCS platoon can maintain situational awareness in its area of responsibility.

The ICV platoon's primary mission is to locate the Red Cross convoy in the south, with UN dignitaries and bring it to the RCP. The ICV platoon has primary responsibility for the area south of Phase Line Alpha. There may be fog in the south of the ICV platoon's sector.

You must move aggressively to identify entities detected in your area of responsibility. I will be engaging in dialog with a local tribal ruler for the next few hours, but monitoring your message traffic. Please keep me informed of activity in your area of responsibility, but feel free to engage in cross talk with the other platoon leaders and take actions to complete the mission, within my intent. ROEs are that you must identify a target as enemy before engaging it.

Table C-1. Platoon data.

Platoon	Vehicles	Sensors	Dismounts	Capability of Dismounts
R&SV	3 R&SVs	3 SUGVs 3 Class I UAVs 1ARV-RSTA	17	Interrogation, engaging dismounts
MCS	3 MCS	1 ARV-A	0	NA
ICV	1 C2V 4 ICVs	1 ARV-A 1 Class I UAV 1 Class II UAV	38	Engaging dismounts

Table C-2. Vehicle data.

Vehicle	Crew	Dismounts	Weapon(s)	Weapons Range	Capable of Destroying
R&SV	2	4-5 scouts	25 mm gun air burst	1.5 km	Dismounts, trucks, light armor
MCS	2	0	BLOS rounds Main Gun	16 km 2 km 700 m	Heavy armor Heavy armor, vehicles and Dismounts & infantry
ICV	2	9	25 mm	1.5 km	Dismounts, trucks, light armor
C2V	3	2	25 mm	1.5 km	Dismounts, trucks, light armor
T-90 Tank	3	0	120 mm Main Gun 50 Cal	3 km 2 km	Heavy armor Dismounts

Table C-3. Sensor systems.

Platform	Operational Range (from controller)	Target ID range	Capable of Destroying
Class I UAV	8 km	500 m	NA
Class II UAV	16 km	3 km	NA
SUGV	1km	1km	NA
ARV-R	2 km	1km	Dismounts, trucks, light armor at 1.5 km
ARV-A	2 km	1km	Heavy armor at 1 km; Dismounts and trucks at 2 km

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Appendix D. Multiple Choice Test Items

1. What is the maximum range that a Class I UAV can identify a target?
   a. 8 km
   b. 16 km
   c. 3 km
   d. 0.5 km

2. Which platoon can fire BLOS rounds?
   a. Recon
   b. MCS
   c. ICV
   d. All the above

3. What is the maximum range that a Class II sensor can identify a target?
   a. 8 km
   b. 16 km
   c. 3 km
   d. .5 km

4. Which platoon has three Class I UAVs?
   a. Recon
   b. MCS
   c. ICV
   d. None

5. Which platoon has an ARV-A?
   a. Recon
   b. MCS
   c. ICV
   d. b and c

6. Which platoon can destroy heavy armor at over 1 km?
   a. Recon
   b. MCS
   c. ICV
   d. None

7. Which platoon has one Class I UAV?
   a. Recon
   b. MCS
   c. ICV
   d. None

8. What is the maximum range of a BLOS round?
   a. 20 km
   b. 16 km
   c. 8 km
   d. 4 km

9. What are the rules of engagement for this vignette?
   a. Deadly force is prohibited
   b. Any target detected can be engaged
   c. Any target identified as enemy can be engaged
   d. Any target not identified as friendly can be engaged

10. Which platoon can interrogate personnel (e.g., refugees)?
   a. Recon
   b. MCS
   c. ICV
   d. All the above

11. Which platoon has 38 dismounts?
   a. Recon
   b. MCS
   c. ICV
   d. None

12. Which platoon can engage dismounts?
   a. Recon
   b. MCS
   c. ICV
   d. All the above

13. Which platoon has a C2V?
   a. Recon
   b. MCS
   c. ICV
   d. None

14. Which platoon has 3 SUGVs?
   a. Recon
   b. MCS
   c. ICV
   d. All the above

15. What can an ARV-A destroy?
   a. Heavy armor
   b. Trucks
   c. Dismounts
   d. All the above

Appendix E. Vignette Descriptions

Vignette 1

- Reconnaissance platoon area: An icon appears indicating an enemy tank 8 kilometers to the north, moving south.
- MCS platoon area: An icon appears indicating six unidentified tracked vehicles 20 kilometers to the north, moving south.
- ICV platoon area: An icon appears indicating four Red Cross wheeled vehicles east of a stream. Another icon appears indicating an unidentified wheeled vehicle under a bridge over the stream, sighted by the ARV-A. The river and bridge are between the ICV platoon and the four wheeled vehicles (Red Cross convoy). Another icon indicates 6 unidentified wheeled vehicles in the south. The ICV platoon has clearly moved in their direction, as noted from the last screen.

Vignette 2

- Reconnaissance platoon area: The ARV-(R) indicates an unidentified tracked vehicle (one icon in reconnaissance platoon sector). Near this vehicle are a group of refugees (one icon).
- MCS platoon area: The unknown tracked vehicle is identified as a friendly (coalition) tank (icon). A group of refugees are located in the MCS platoon area (icon).
- ICV platoon area: The ICV platoon is escorting the Red Cross vehicles back to the RCP. An enemy tank is located between the ICV platoon and the RCP (icon).

Vignette 3

- Vehicle by refugees is coalition vehicle. Two RSTA vehicles deployed, one to bring back refugees from MCS area; one to accompany MCS vehicle to barn area.
- Reconnaissance platoon area. About 150 enemy dismounted infantry entering area from north.

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